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Large Scale Spatial Patterns of Conifer Diseases in the Bighorn Mountains, Wyoming

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A roadside reconnaissance for forest diseases in the Bighorn National Forest was conducted in 1991. The most common disorders were dwarf mistletoe, Comandra blister rust, western gall rust, and an undetermined needlecast of lodgepole pine; broom rusts, patch mortality, branch canker, and crown mortality of Engelmann spruce and subalpine fir; and white pine blister rust of limber pine. The most widespread disorders showed the greatest diversity across the forest. Two or more disorders (average = 4) occurred concurrently on all townships.

Keywords: Bighorn Mountains, forest diseases, disease survey, roadside survey, biodiversity, forest disease, diversity, epidemiology, disease complexes.

Introduction

Information on tree diseases in the Bighorn National Forest, Wyoming, is scant. Previous published studies have dealt with dwarf mistletoe (Hawksworth 1958; Johnson *et al.* 1979), Comandra blister rust (Andrews and Harrison 1959), and white pine blister rust (Brown 1978). Information also can be found in accession lists of the U.S. Forest Service, Forest Pathology Herbarium, Fort Collins (FPF) and other unpublished sources. However, none of this information is spatially well-referenced; as such, little can be concluded about the large scale, forestwide distributions of tree diseases in this forest, or how various forest pests may interact. This report locates landscape scale zones of forest pest interaction.

Methods

During the summer of 1991, I conducted a roadside reconnaissance for forest diseases by modifying Hawksworth's (1958) procedures. Trees within 1 to 2 chains of both sides of a road were observed while driving slowly (usually less than 10 miles per hour). Roads were chosen to cover most accessible parts of the Bighorn National Forest. Diseased stands were located and marked on a forest map, which was used for subsequent analyses.

I used procedures described by Lundquist (1991a,b) to summarize disease intensity and evaluate large scale geographic patterns of disease distribution. Briefly, the number of diseased stands in each township was divided into the road miles surveyed and disease incidence was calculated as the average number of stands per road mile per township. I summarized data in maps that showed intensity of occurrence among townships.

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Disease diversity (based on variability among townships) was calculated by using the following indices:

1. Shannon-Weaver Index (H') (Shannon and Weaver 1949), modified for landscape habitat diversity by Pielou (1975),

$$H' = - \sum (a_i / A_t) \log (a_i / A_t)$$

where a_i = number of townships with disease intensity (i) and A_t = total number of townships surveyed.

2. Simpson Index (L), modified for finite sample sizes (Simpson 1949; Christensen and Peet 1982),

$$L = \sum (a_i (a_i - 1)) / (A_t (A_t - 1))$$

H' varies directly with heterogeneity and L varies inversely with heterogeneity; higher values of H' and lower values of L signify higher diversity. Furthermore, H' is not range delimited, but L varies only between 0 and 1.

The prevalence of disorder combinations was calculated as a proportion of number of townships in which both disorders occur versus number of townships in which one or the other disorder or both were present. Independence among disorder occurrences within townships was tested using a Chi square test. The relationship between disorders based on average number of sightings per road mile per township was examined using linear regression analysis. The data were analyzed using the Statistical Graphical System (Statistical Graphics Corporation 1991). Differences were judged to be statistically significant at $p < 0.05$.

Observations

A total of 1393 disease sightings were made along 759 miles of forest roads in 45 townships. Inaccessible townships, which were mainly in the Cloud Peak Wilderness Area, were not examined. The most common forest diseases were dwarf mistletoe (*Arceuthobium americanum* Nutt. ex. Engelm.) on lodgepole pine (*Pinus contorta* Douglas ex Loud.); Comandra blister rust (*Cronartium comandrae* Peck) on lodgepole pine; broom rust (*Melampsorella caryophyllacearum* J. Schroet.) on subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.); broom rust (*Chrysomyxa arctostaphyli* Dietel) on Engelmann spruce (*Picea engelmannii* Parry ex Engelm.); western gall rust (*Peridermium harknessii* J.P. Moore) on lodgepole pine; the introduced white pine blister rust (*Cronartium ribicola* J.C. Fisch.) on limber pine (*Pinus flexilis* James); an undetermined needlecast on lodgepole pine; and branch canker on subalpine fir (cause unknown). Causes were not known for the observed mortality and crown top death of spruce and fir. Other minor diseases were not noted.

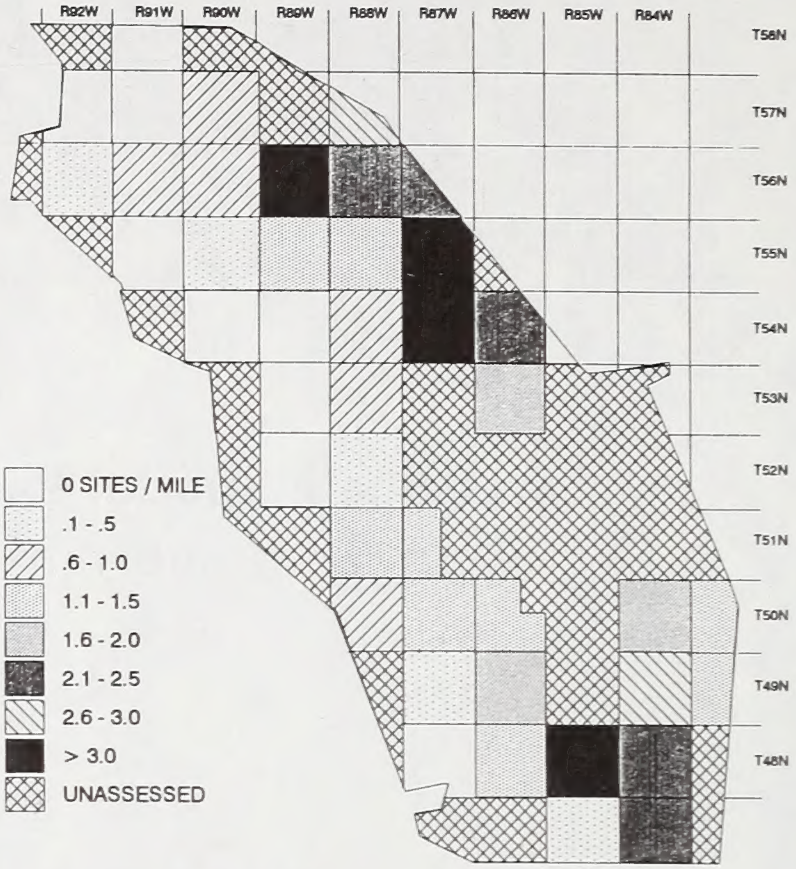

Figure 1.—Distribution of Comandra blister rust of lodgepole pine among townships within the Bighorn National Forest.

Comandra Blister Rust

Comandra blister rust was the most widely distributed tree disease encountered during this survey, occurring in 35 townships (fig. 1). Disease intensity varied considerably across geographic locations (H' = 0.85, table 1), reaching as high as 3.5 stands per road mile with peaks of relatively high intensity near Fool Creek (T56N R89W & T57N R88W), Lookout Mountain (T54N R87W & T55N R87W), and Crazy Woman Creek (T49N R84W & T48N R85W). The incidence of Comandra blister rust was correlated ($p < 0.05$) with the incidence of dwarf mistletoe (r = 0.56), western gall rust (r = 0.37), and pine needlecast (r = 0.52, table 2).

According to accession records in the FPF, *C. comandrae* was collected as early as 1955 and at the following locations: Canyon Creek (T49N R83W), Meadowlark Lake (T49N R86W), and Doyle Creek (T47N R84W). Previously published accounts note this disease in the Tongue Ranger District and Buffalo Ranger District around 1957 (Andrews and Harrison 1959).

Dwarf Mistletoe

Dwarf mistletoe on lodgepole pine was common and one of the most spatially diverse (H' = 0.756, table 1) tree diseases noted in this survey. The disease was found in 32 townships (fig. 2) and disease intensity

Table 1. Shannon-Weaver (H′) and Simpson (L) Index of Diversity values and total number of townships with the presence of disorders in the Bighorn National Forest. H′ is directly correlated with diversity and L is inversely correlated with diversity. Higher values of H′ and lower values of L signify higher diversity. L varies between 0 and 1, but H′ is not limited.

Disorder	Number of townships	Disease stands per mile (+s.d.)	H′	L
Comandra blister rust	34	1.47 (0.94)	0.850	0.134
Dwarf mistletoe	33	0.97 (0.63)	0.756	0.170
Broom rust	34	0.62 (0.51)	0.591	0.270
Patch mortality	27	0.99 (0.79)	0.703	0.217
Western gall rust	14	0.37 (0.33)	0.350	0.530
White pine blister rust	7	0.76 (0.61)	0.259	0.715
Pine needlecast	19	0.24 (0.20)	0.360	0.459
Branch canker	7	0.29 (0.25)	0.215	0.725
Crown death	12	0.20 (0.31)	0.278	0.590

Table 2. Prevalence of various disorder combinations in the Bighorn National Forest. Number of townships in which various disorder combinations occur (concurrent), one or the other or both occur (total), prevalence (concurrent/total), coefficient of correlation (r) and significance level (p). DM = dwarf mistletoe, CR = Comandra blister rust, WGR = western gall rust, ND = pine needlecast, PM = patch mortality, BR = broom rusts, BC = branch canker, CM = crown mortality.

Disorder combination		Number of townships Concurrent	 Total	Percentage prevalence
Pine disorders	DM X CR	30	37	0.80
	DM X WGR	13	34	0.38
	DM X ND	19	35	0.54
	CR X WGR	14	34	0.41
	CR X ND	21	34	0.62
	WGR X ND	11	25	0.44
Spruce disorders	PM X BR	22	39	0.56
	PM X BC	7	27	0.26
	PM X CM	10	33	0.30
	BR X BC	6	35	0.17
	BR X CM	9	37	0.24
	BC X CM	4	14	0.29

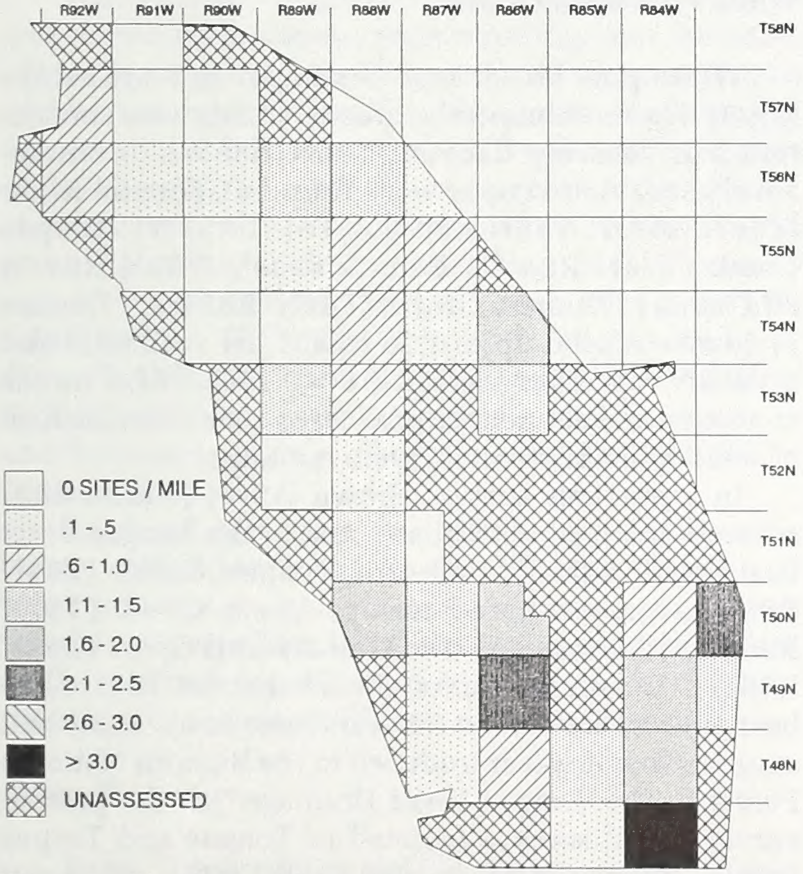

Figure 2.—Distribution of dwarf mistletoe of lodgepole pine among townships within the Bighorn National Forest.

ranged up to 2.76 stands/mile. The most commonly infected stands were concentrated near Fool Creek (T56N R89W & T56N R88W), Big Goose (T54N R86W), Cold Spring Campground (T50N R88W), Deer Park (T49N R86W & T50N R86W), Tie Hack Campground (T50N R83W), Crazy Woman Creek (T49N R84W, T48N R84W & T47N R84W), and Hazelton Pyramid (T48N R84W). The incidence of dwarf mistletoe was significantly correlated with Comandra blister rust (r = 0.56) and pine needlecast (r = 0.34, table 2).

More research has focused on dwarf mistletoe than any other tree disease in this forest. Hawksworth (1958) and Johnson *et al.* (1979) assessed the occurrence and intensity of dwarf mistletoe using roadside reconnaissance and road plot surveys. Both studies indicated that this disease was widespread and destructive, but less so than on other National Forests in Wyoming. In the survey by Hawksworth (1958), 23% of 42 miles in the Tongue Ranger District, 35% of 29 miles in the Tensleep Ranger District, 32% of the 42 miles in the Buffalo Ranger District, and 34% of 33 miles in the Goose Ranger District had trees infected with dwarf mistletoe.

Broom Rusts of Subalpine Fir and Engelmann Spruce

Broom rusts of fir and spruce were found throughout the northern, western, and southern sections of the Bighorn National Forest. These diseases were found in 34 townships (fig. 3). Disease intensity ranged up to 2.76 stands per road mile, and diversity was moderate (H′ = 0.591). Peaks of relatively high disease intensity occurred at Leaky Mountain (T57N R90W), Finger Creek (T54N R89W), and Johnny Creek (T52N R89W, T52N R88W & T51N R88W). Highest disease incidence occurred near Paint Rock Lakes (T51N R88W). Apparently, neither *C. arctostaphyli*, the causal agent of spruce broom rust or *M. caryophyllacearum*, the causal agent of fir broom rust, has been studied in the Bighorn National Forest.

Western Gall Rust

Western gall rust of lodgepole pine was noted in 15 townships (fig. 4). Disease incidence ranged up to 1.0 stand per road mile, and diversity was relatively low (H′ = 0.35). This disease had a large-scale, patchy distribution, and occurred primarily across the eastern half of the forest. The most intensely infected area was noted near Tie Hack Campground (T50N R83W). Less intensely infected stands occurred near Doyle Creek (T47N R84W), Big Goose (T54N R85W & T54N R86W), Shell Creek (T53N R88W), Dayton Creek (T56N R90W), and High Park (T48N R86W).

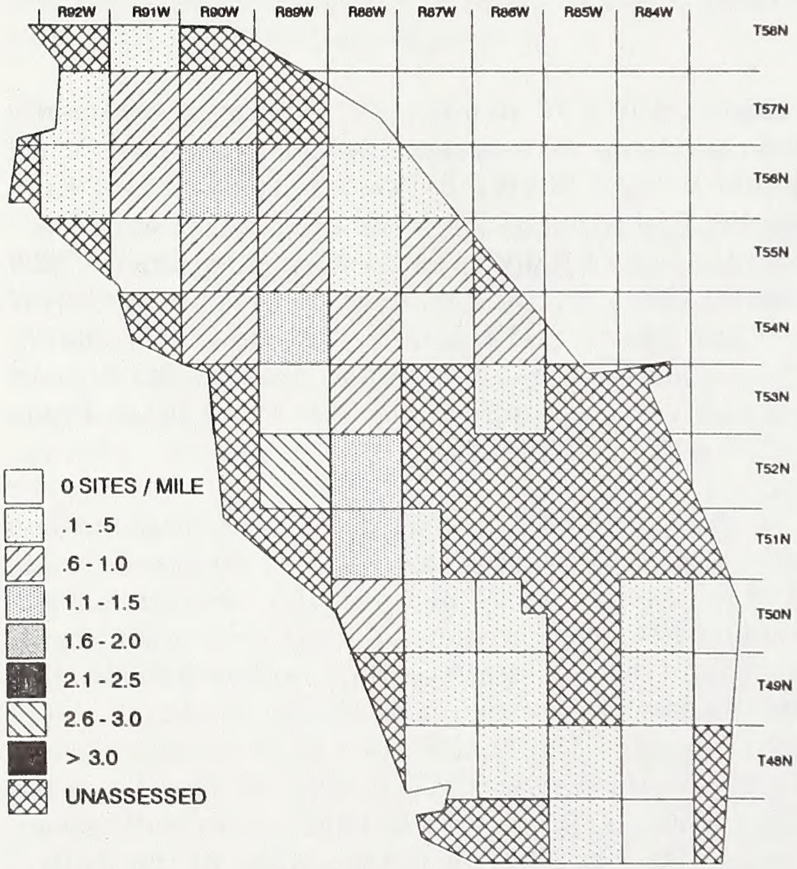

Figure 3.—Distribution of broom rust of Engelmann spruce and subalpine fir among townships within the Bighorn National Forest.

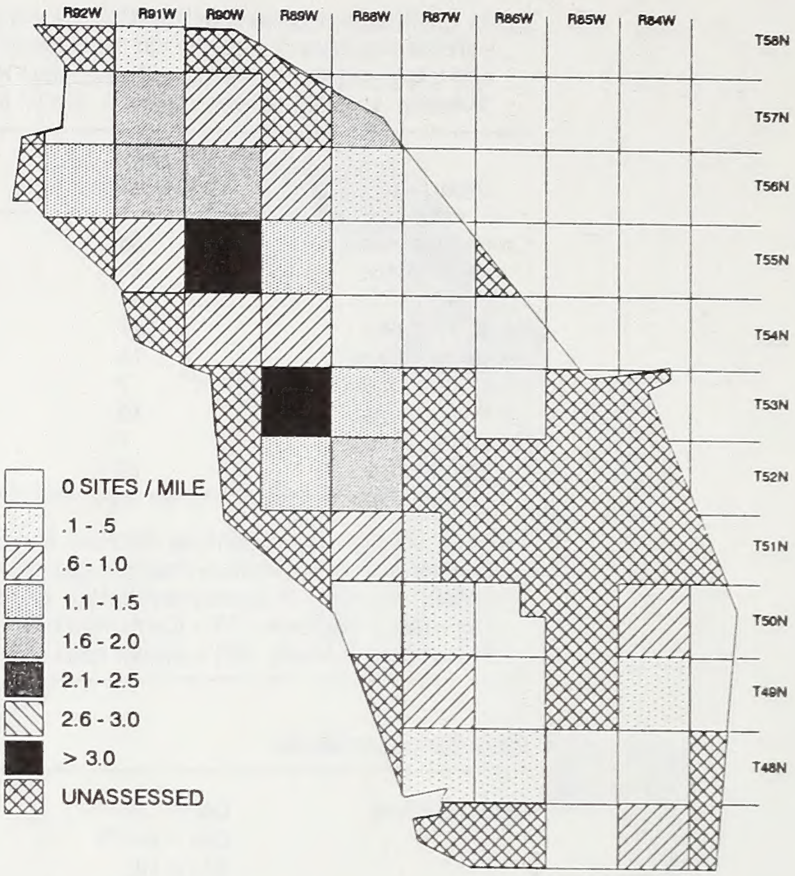

Figure 4.—Distribution of patch mortality of Engelmann spruce and subalpine fir among townships within the Bighorn National Forest.

According to accession records at the FPF, *C. harknessii* was collected as early as 1957 at Doyle Creek. Apparently, however, no published records exist of this fungus in the Bighorn National Forest.

White Pine Blister Rust

White pine blister rust was found in 9 townships (fig. 5). The most intensely infected stands were concentrated at Tensleep Canyon (T48N R86W). Less severely infected stands were found at Tongue River (T56N R87W, T56N R88W & T55N R88W), Teepee Creek (T54N R85W), Ranger Creek (T53N R88W) and Crazy Woman Creek (T49N R83W). Disease incidence ranged up to 1.25 stands per road mile and diversity was relatively low (H′ = 0.259). Notes on the condition and abundance of *Ribes* sp., the alternate host of white pine blister rust, were not taken.

In a previous survey, Brown (1978) found stands severely infected with blister rust in the Tongue River Drainage (T56N R87W) and Teepee Creek (T54N R85W), one cankered tree at Mann Creek (T57N R90W), and one cankered tree at Shell Creek (T53N R89W). Brown presents evidence that the disease had been present for at least 30 years prior to his study and suggests that it was introduced to the Bighorn National Forest in the Tongue River Drainage. In the present survey, the disease was noted in Tongue and Teepee Creeks, but not at Mann and Shell Creeks. A recent report (Lundquist and Lister 1991) indicates that white

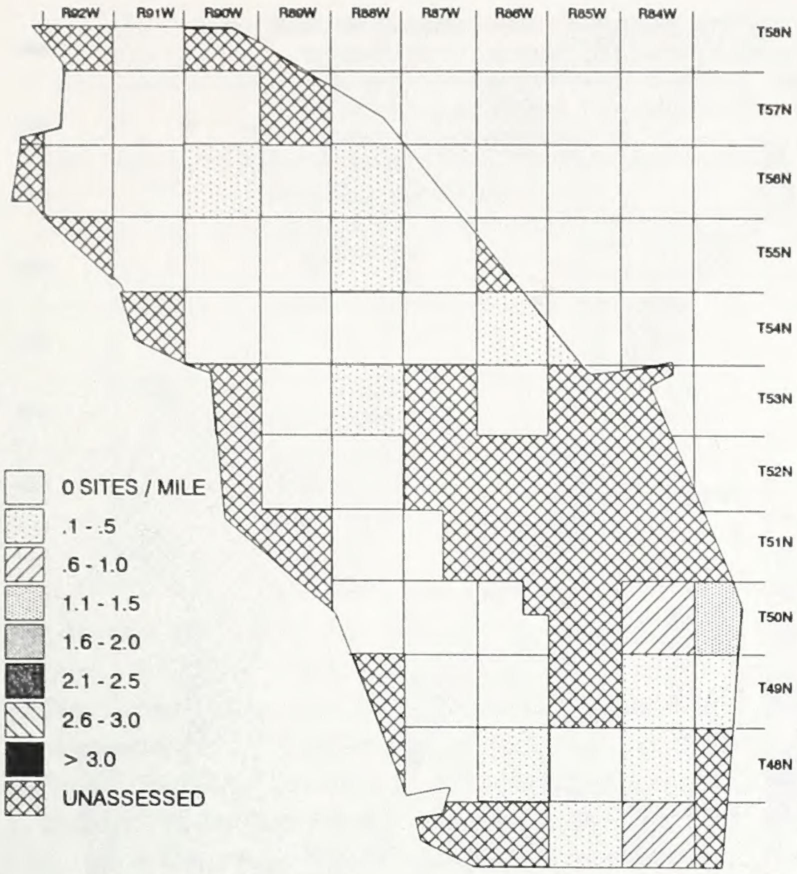

Figure 5.—Distribution of western gall rust of lodgepole pine and ponderosa pine among townships within the Bighorn National Forest.

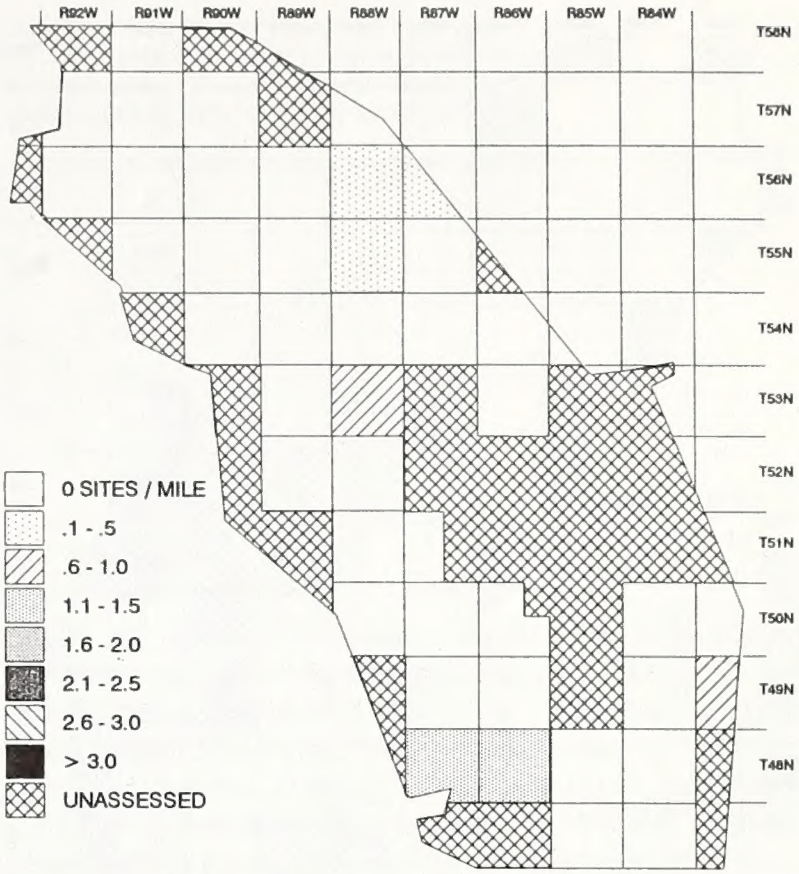

Figure 6.—Distribution of white pine blister rust of limber pine among townships within the Bighorn National Forest.

pine blister rust incidence at Tensleep Canyon increased dramatically in the last 3 or 4 years.

Patch Mortality of Spruce and Fir

The disorder referred to here as "patch mortality" was identified by canopy gaps resulting from the death of small groups of trees. This condition was noted in 28 of the 45 surveyed townships (fig. 6). Disease intensity ranged up to 3.5 sightings per road mile, diversity was high (H′ = 0.703), and the most commonly infected stands occurred in the northern sections of the surveyed area. Relatively high concentrations of this disorder occurred near Hidden Teepee Creek (T55N R89W, T56N R90W, T56N R91W & T57N R91W), Sawmill Flats (T57N R88W), and Granite Creek (T53N R89W & T52N R88W). Apparently, patch mortality of spruce and fir has not previously been described in the Bighorn National Forest.

Dead and dying trees associated with this disorder were examined for the presence of insects, diseases, or other possible causes, but none of these causes were consistently associated with the condition. Differences in their large scale distributions suggest that the four disorders of spruce and fir are not related.

Other Disorders

Three other widespread disorders were noted during this survey. These were a needlecast of lodgepole pine (fig. 7), crown top death of Engelmann spruce and subalpine fir (fig. 8), and a branch canker disease of subalpine fir (fig. 9). Causes for these disorders are currently unknown.

Disease Complexes

Two or more disorders occurred concurrently on all townships (fig. 10). The overall average number of diseases per township was 4. The most commonly overlapping pine disorders were Comandra blister rust and dwarf mistletoe (table 2 and 3). The most common overlapping spruce/fir disorders were patch mortality and broom rust (table 2 and 3). The heaviest zones of overlap for all diseases occurred at Fool Creek (T56N R88W, T56N R89W, and T56N R90W), Shell Creek (T53N R88W), and High Park (T48N R86W) (fig. 10).

Discussion and Conclusions

This survey design was similar to that used recently in the Black Hills National Forest (Lundquist 1991a,b). Unlike the Black Hills National Forest, however, many locations in the Bighorn National Forest were not surveyed because of their inaccessibility. Therefore, we do not know how closely our distribution maps represent actual disease distributions in inaccessible areas.

Because pests are a primary source of discontinuities in stand structure, they are important natural sources of

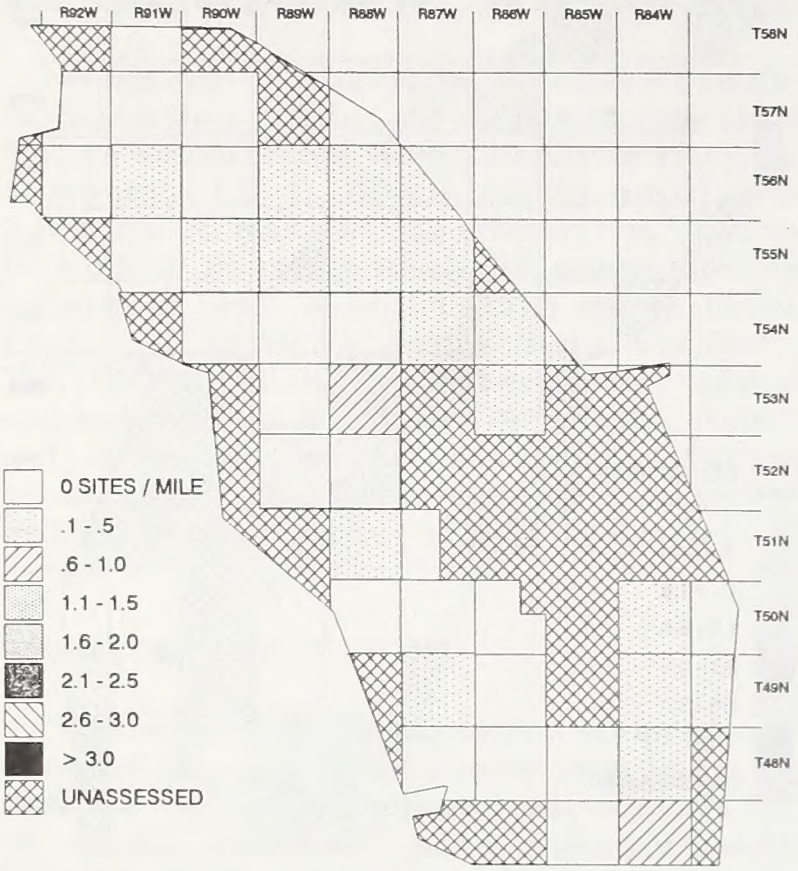

Figure 7.—Distribution of lodgepole pine needlecast among townships within the Bighorn National Forest.

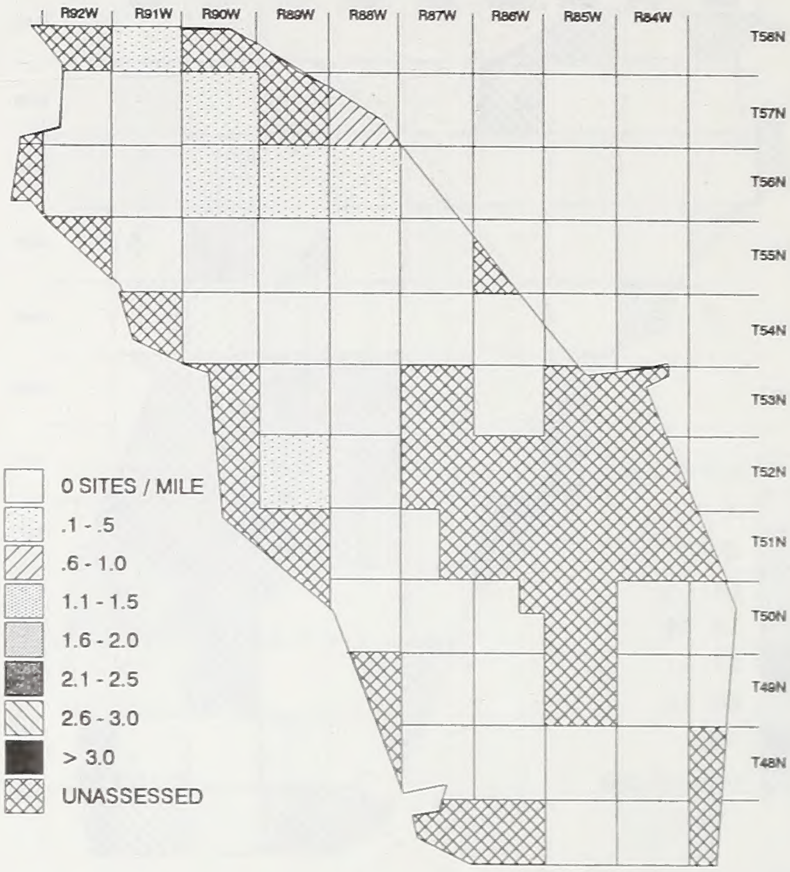

Figure 9.—Distribution of branch canker of subalpine fir among townships within the Bighorn National Forest.

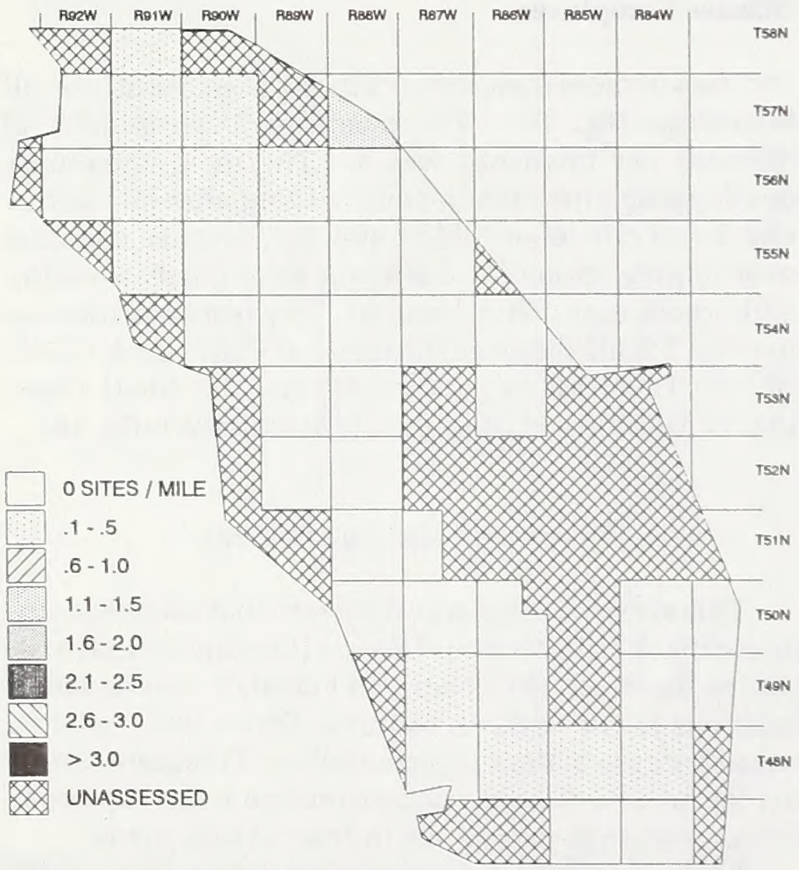

Figure 8.—Distribution of a disorder of Engelmann spruce and subalpine fir causing crown tops to die.

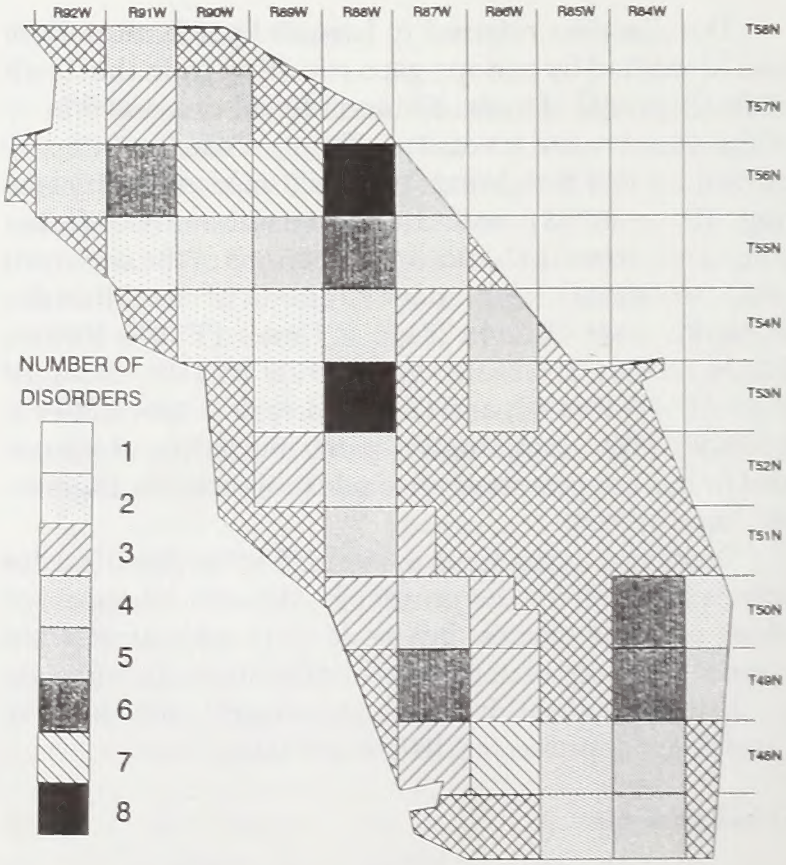

Figure 10.—Distribution of townships with disorders occurring concurrently. Each township was scored according to the number of disorders occurring within it.

Table 3. Relationship between the intensities of various disorders in the Bighorn National Forest. Values for coefficient of correlation (r) and significance level (p) are based on number of sightings per road mile per township for each disorder. DM = dwarf mistletoe, CR = Comandra blister rust, WGR = western gall rust, ND = pine needlecast, PM = patch mortality, BR = broom rusts, BC = branch canker, CM = crown mortality.

Disorder Combination		**r**	**p**
Pine disorders	DM X CR	0.56	0.0001
	DM X WGR	0.28	0.0639
	DM X ND	0.34	0.0233
	CR X WGR	0.37	0.0133
	CR X ND	0.52	0.0003
	WGR X ND	0.32	0.0318
Spruce disorders	PM X BR	0.13	0.4130
	PM X BC	0.35	0.0218
	PM X CM	0.28	0.0694
	BR X BC	0.09	0.5717
	BR X CM	0.03	0.8305
	BC X CM	0.43	0.0035

landscape diversity. In the survey described in this report, different disorders displayed different large-scale patterns of occurrence and severity. Generally, the most widespread diseases have the greatest diversity. More widespread disorders are more likely to encounter a greater abundance and variety of factors that can influence their spatial and temporal distribution. The distribution of Comandra blister rust, for example, is influenced by the distribution of its alternate host (*Comandra umbellata*). Similarly, the distribution of dwarf mistletoe is influenced by stand and fire management history (Alexander and Hawksworth 1975).

The Shannon-Weaver (Shannon and Weaver 1949) and Simpson (Simpson 1949) indices of general diversity are used here to quantify variability in disorder distribution (table 1). Both indices indicated that wider distributions (higher number of townships) were directly correlated with greater diversity at the landscape level ($r^2 = 0.88$, $p < 0.001$; table 1). Consequently, Comandra blister rust, dwarf mistletoe, and patch mortality showed relatively high levels of diversity and had wide distributions; broom rusts had moderate levels of diversity and moderate distribution; and western gall rust, white pine blister rust, pine needlecast, branch flagging, and crown death had low diversity and restricted distributions.

Several studies have shown that disturbance agents are often coupled concurrently or sequentially in time and space (Cobb *et al.* 1974; Filip and Goheen 1987; Goheen and Filip 1980; Hudak and Wells 1974; Kulhavy et al. 1984; Leininger *et al.* 1990; Redfern 1978; Sinclair and Hudler 1988; Tkacz and Schmitz 1986; and Wargo and Houston 1974). Indeed, overlapping disorders are common in the Bighorn National Forest. Behavior and impact of disorders may differ within zones of overlap from areas outside, because interactions among disorders are more probable within these zones.

Knowledge of the existence and locations of interacting disorders has much potential importance. For example, individual pest models used concurrently might not adequately predict impact, because simple addition may not adequately characterize the impact of two or more disorders interacting. Although models have been developed for dwarf mistletoe, western spruce budworm, Douglas-fir tussock moth, mountain pine beetle, southern pine beetle, root disease, western pine beetle, gypsy moth, eastern spruce budworm, fusiform rust, and air pollution (Eav *et al.* 1989), multiple pest complex models are just now being developed. One rule for such models might be that probabilities of different combinations of disorders occurring concurrently differ among different locations across the landscape. Another rule might be the greater the number of pests, the greater the potential for qualitative and quantitative variability within the forest. Predictive models should reflect these types of rules, which are not considered in current single-pest, stand-based models. A large-scale analysis of distribution would be useful in determining where overlaps occur.

Pest interactions are scale dependent. Scales as small as the individual tree may be useful in examining cause and effect, but larger scales may be necessary for incorporating pest information into management decisions. Forest management decisions are usually based on management units or GIS polygons, which are composed of groups of stands. Similarly, yield and growth models predict stand behavior, as do current pest impact models. It may be necessary to define "interaction" for a scale useful to management. Individual tree-based models or stand models based on individual tree data may not capture interactions where two or more pests alter stand production but never actually come into contact.

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